T01/10

May 2001

THE EFFECT OF ENERGY DEFICIT ON PHYSICAL PERFORMANCE AT SEA LEVEL AND 4,300 M ALTITUDE

DISCLAIMERS

Approved for public release; distribution is unlimited.

The views, opinions and/or findings contained in this publication are those of the authors and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

For the protection of human subjects, the investigators adhered to policies of applicable Federal Law CFR 46.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
30 May 01

3. REPORT TYPE AND DATES COVERED
2001

4. TITLE AND SUBTITLE
Effect of Energy Deficit on Physical Performance at Sea Level and 4300 m Altitude

5. FUNDING NUMBERS

6. AUTHOR(S)
Charles S. Fulco, Anne Friedlander, Stephen R. Muza, Paul B. Rock, Scott Robinson, Eric Lammi, Carol J. Baker-Fulco, Jay MacDonald, Kenneth Kambis, Barry Braun, Steven F. Lewis, Gail Butterfield, and Allen Cymerman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Institute of Enviromental Medicine
Natick, MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Material Command
Fort Detrick
Frederick, MD 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

We investigated the effect on physical performance of 3 weeks of severe deficit energy intake at sea level (SL) and high altitude (HA, 4300 m). Twenty-six young healthy men (range: 18 to 34 yrs) were assigned for 3 weeks to one of 3 dietary and environmental groups. One group consumed adequate kcal/day to maintain body weight while living at HA (ADQ, n=7) and two groups consumed 1500 kcal/day less than needed to maintain body weight while living at SL (HYPO, n=9) or HA (DEF, n=10). For all groups, physical performance was assessed at SL prior to dietary phase assignment (i.e., baseline), and on days 2, 10 and 20 of the dietary phases. The physical performance tasks were: 1. maximal oxygen uptake (VO2max), 2. time to complete 50 lift and carry cycles, 3. number of one-arm elbow flexions (10% body weight at 22 flexions/min), and 4. adductor pollicis muscle exercise (repeated 5 sec static contractions at 50% of maximal force / 5 sec rest). After 3 weeks, relative to the baseline phase, the HYPO and DEF groups lost nearly 5% and 8% body weight, respectively; and 3% and 6% lean body mass, respectively. The body weight and lean body mass losses of the HYPO and DEF groups were significantly greater than those of the ADQ group ($P<0.01$), who lost neither body weight nor lean body mass ($P>0.05$). VO2max was not impaired during body weight loss for the HYPO group ($P>0.05$) whereas VO2max declined by 30% on day 2 of HA exposure compared to the SL baseline phase for the ADQ and DEF groups. However, VO2max for either the ADQ or DEF group did not change with continued HA exposure ($P>0.05$). Time to complete the lift and carry task was impaired for the ADQ and DEF groups on day 2 of HA exposure ($P<0.05$) but subsequently improved ($P<0.05$) for both groups similarly with continued HA exposure. One-arm elbow flexion and adductor pollicis muscle performance tasks did not differ among groups either before or during the dietary phases ($P>0.05$). We conclude that significant lean body mass losses due to three weeks of underfeeding do not impair maximal or submaximal physical performance either at SL or during the first 3 weeks of exposure to HA.

14. SUBJECT TERMS
Diet, Underfeeding, Energy Deficit, Altitude, Hypoxia, Exercise Performance

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

USARIEM TECHNICAL REPORT T01-10

EFFECT OF ENERGY DEFICIT ON PHYSICAL PERFORMANCE AT SEA LEVEL AND 4,300 M ALTITUDE

Charles S. Fulco
Anne Friedlander
Steven R. Muza
Paul B. Rock
Scott Robinson
Eric Lammi
Carol J. Baker-Fulco
Jay McDonald
Kenneth Kambis
Barry Braun
Steven F. Lewis
Gail Butterfield
Allen Cymerman

THERMAL AND MOUNTAIN MEDICINE DIVISION

May 2001

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

BACKGROUND

The current study was performed in the first year of a three-year collaborative research project between the Palo Alto Veterans Health System (PAVA, Palo Alto, CA) and the U.S. Army Research Institute of Environmental Medicine (USARIEM, Natick, MA). The entire project *"Effect of Energy Deficit on Work Performance at 4,300 m Elevation"* was funded by a three-year grant awarded to the PAVA and the USARIEM by the Cooperative VA/DoD Medical Research Program in the area of physiological foundations of physical performance and combat readiness.

The overall purpose of the project in the first year was to evaluate the effects of a severe energy deficit (approximately -1500 Kcal•day^{-1} or 40% of weight stabilization need) at sea level and combined with three weeks of high altitude exposure (4,300 m) on physical and mental performance. Included were measures of whole-body and isolated muscle group exercise performances, body composition, acute mountain sickness, respiratory muscle performance, substrate metabolism, postural stability, and mood states. Presented in this report are the results of two whole-body and two isolated muscle performance tasks. In addition, some of the body composition changes associated with weight loss are presented.

ACKNOWLEDGMENTS

The authors would like to thank the subjects for their outstanding participation in a particularly arduous research investigation.

EXECUTIVE SUMMARY

Conditions in the modern military require soldiers to operate at levels of intense physical activity for sustained periods of time. Any factor that degrades physical performance can be a serious impediment to combat effectiveness. Inadequate food intake and the resulting losses in body weight and lean body mass have been implicated as such factors. The objective of this investigation, therefore, was to evaluate the effect on physical performance of three weeks of a severe deficit energy intake at sea level and at high altitude (4300 m).

Twenty-six young healthy men (mean: 22 yrs; range: 18 to 34 yrs) were assigned for three weeks to one of three dietary and environmental groups. One group consumed adequate kcal•day^{-1} to maintain body weight while living at altitude (ADQ, n=7) and two groups consumed -1500 kcal•day^{-1} less than needed to maintain body weight while living at sea level (HYPO, n=9) or altitude (DEF, n=10). For all groups, physical performance was assessed at sea level prior to dietary phase assignment (i.e., baseline), and on days 2, 10 and 20 of the dietary phases. The physical performance tasks were: 1. maximal oxygen uptake ($\dot{V}O_{2max}$; cycle ergometry), 2. time to complete 50 lift and carry cycles, 3. number of one-arm elbow flexions (10% body weight at 22 flexions•min^{-1}), and 4. adductor pollicis muscle exercise (repeated 5 sec static contractions at 50% of maximal force / 5 sec rest).

After three weeks, relative to the baseline phase, the HYPO and DEF groups lost nearly 5% and 8% body weight, respectively; and 3% and 6% lean body mass, respectively. The body weight and lean body mass losses of the HYPO and DEF groups were significantly greater than those of the ADQ group ($P<0.01$), who lost neither body weight nor lean body mass ($P>0.05$). $\dot{V}O_{2max}$ was not impaired during body weight loss for the HYPO group ($P>0.05$) whereas $\dot{V}O_{2max}$ declined by 30% on day 2 of altitude exposure compared to the sea-level baseline phase for the ADQ and DEF groups. However, $\dot{V}O_{2max}$ for either the ADQ or DEF group did not change with continued altitude exposure ($P>0.05$). Time to complete the lift and carry task was impaired for the ADQ and DEF groups on day 2 of altitude exposure ($P<0.05$) but subsequently improved ($P<0.05$) for both groups similarly with continued altitude exposure. One-arm elbow flexion and adductor pollicis muscle performance tasks did not differ among groups either before or during the dietary phases ($P>0.05$).

We conclude that significant lean body mass losses due to three weeks of underfeeding do not impair maximal or submaximal physical performance either at sea level or during the first three weeks of exposure to 4300 m altitude.

INTRODUCTION

Conditions in the modern military require soldiers to operate at levels of intense physical activity for sustained periods of time. Any factor that degrades this ability is a serious impediment to combat effectiveness. Inadequate food intake has been implicated as a potential factor (8). Soldiers in the field typically consume much less energy than they expend (1). This problem is exacerbated at high altitude where energy balance is more difficult to attain due to reduced appetite and increased basal energy requirements (2;4). An energy deficit that results in large losses in body weight and lean body mass may cause impairments in physical performance that are in addition to those associated with altitude exposure alone. Studies of high altitude exposure in humans with and without significant losses in body weight and lean body mass have been reported (5); but the potential differences in physical performance have never been compared experimentally in the same investigation. Moreover, incomplete or inconsistent findings among previous reports make it difficult to predict *a priori* the effects of prolonged intake energy deficit on physical performance at altitude.

OBJECTIVES

The primary objective of this study was to evaluate the effect of a daily deficit energy intake (~ 40% of weight stabilization need) combined with three weeks of high altitude exposure on four physical performance tasks. A secondary objective was to evaluate energy intake deficit of the same magnitude and duration on the same physical performance tasks; but only at sea level.

METHODS

SUBJECTS

Men and women were recruited during the months of February through June from advertisements and fliers placed in local newspapers and universities in and around the Palo Alto/San Jose, CA area. As part of the recruiting inclusion/exclusion criteria, all had to be; i) nonsmokers, ii) normal weight for height, iii) 21 to 35 years old, iv) require at least 2700 kcal•day^{-1} for maintenance of body weight, v) weight stable for previous 6 months, vi) in good health with no chronic illnesses, vii) born at an altitude less than 2000 m, viii) residing at or near sea level in the previous three years and not made visits to altitudes greater than 2000 m within the last 3 months, ix) participating in a regular exercise program, and x) able to perform a single repetition of a one-arm strict curl using 50 lbs.

Over a hundred individuals inquired; of these approximately 50 interested individuals came to the laboratory for a verbal briefing and facility tour to become thoroughly familiarized with equipment, procedures, and personnel. If they were still interested in participating in the study, they were asked to sign a consent form approved

by all institutions involved in the research. They then had a physical examination that included a medical history assessment, resting 12-lead electrocardiogram, routine blood and urine analyses, and a nutrition assessment. If all tests proved normal, then the one-arm strict curl was attempted; if successful, then a baseline maximal oxygen uptake ($\dot{V}O_{2max}$) test was performed. Because of an inability of any woman recruited to successfully perform the one-arm curl, the study was performed using only men.

STUDY DESIGN

Subject Groups

Thirty men were studied at sea level at the Aging Study Unit of the Palo Alto VA Health Center in the spring and early summer where all were fed a controlled diet for seven days to attain energy and nitrogen balance, and body weight stabilization. During the stabilization phase, the subjects performed physical performance tests and sea-level (SL) baseline data were recorded. Also recorded were SL baseline data for other related substudies that will be described in other reports.

The original plan was to divide the subjects into three groups of 10 individuals matched as well as possible for $\dot{V}O_{2max}$ after the SL baseline body weight stabilization phase. However, because of scheduling conflicts between study dates and personal affairs of some of the test subjects, their ability to be tested on prescribed dates was also considered before assigning a subject to a particular group. Moreover, by the time actual data collection was in progress either at sea level or altitude (at the USARIEM High Altitude Research Laboratory at the summit of Pikes Peak) in mid to late summer, five subjects had voluntarily withdrawn from the project for personal reasons unrelated to the conditions of the study. Thus, complete data were obtained on only 25 subjects.

After all subjects participated in the body weight stabilization phase at sea level, 9 of the subjects were assigned to the hypocaloric (HYPO) group and consumed for 21 days at sea level a balanced diet that was deficient in energy by approximately 40% of the calories required to maintain body weight (or about -1500 kcal•day^{-1}). (Figure 1). The remaining subjects were assigned to either an energy adequate (ADQ) group (n=7) or an energy deficient (DEF) group (n=10). Both of these groups subsequently resided at altitude for 21 days. While at altitude, the subjects of the ADQ group consumed enough kcal•day^{-1} to maintain body weight while the subjects of the DEF group, like those of the HYPO group at sea level, were provided a diet deficient in kcal•day^{-1} by approximately 40% of the calories required for weight maintenance. *(Note: One individual was first a subject in the HYPO group and then a subject in the DEF group. A period of one month at sea level separated the end of the HYPO phase and the beginning of the DEF phase.)*

FIGURE 1: The Altitude Exposure and Dietary Phase Experimental Time Line

Sea Level		Altitude
7 Days Body Weight Stable Performance Tests Baseline Phase	Days 1 to 21 Performance Tests Dietary Phase	Days 1 to 21 Performance Tests Dietary Phase
HYPO	HYPO	
DEF ADQ		DEF ADQ

Diet

The diet consisted of whole foods provided to each subject in individualized amounts. Protein content of the diet was held constant (1.2 grams of protein•kg body weight^{-1}•day^{-1}) while energy intake was adjusted by adding or subtracting fat and carbohydrate containing foods so that the ratio of these nutrients in the diet remained approximately 1:2, respectively. The body weight maintenance diet therefore consisted of approximately 12% protein, 30% fat, and 58% carbohydrate. During the 21-day dietary phases, the subjects in the HYPO and DEF groups ate approximately 60% of their body weight stabilization diet; while the subjects in the ADQ group ate their body weight stabilization diet. Energy deficit was created by decreasing the intake of fat and carbohydrate foods, but keeping the carbohydrate intake at least 3 gm•kg^{-1}•day^{-1} to minimize the effect of low carbohydrate intake on glycogen stores. In addition, during the dietary phases at altitude, the subjects in the DEF and ADQ groups ate an extra 200 kcal•day^{-1} to account for the altitude-induced increase in metabolic rate (4). To insure adequate intake of nutrients under reduced energy intake conditions, a multi-vitamin and mineral supplement was provided daily.

Travel to Altitude

All ADQ and DEF subjects were flown in groups of two each day to Colorado Springs, CO and spent the night at 1,800 m in an apartment while on supplemental oxygen supplied by an oxygen concentrator to maintain sea level oxygen saturation levels. In the mornings, the pair was driven to the summit of Pikes Peak (4,300 m), while still breathing oxygen via a mask. Immediately after arriving on the summit, one of the subjects removed his mask, and within an hour, began the glucose, glycerol, and protein isotope turnover studies (results to be presented in other reports). The other subject continued breathing supplemental oxygen until about an hour before he was scheduled to begin the isotope trials (approximately 4 hours after arrival at the summit). To better maintain moral at altitude, data collection on all subjects in the DEF group was completed before data collection on subjects in the ADQ group was begun.

Programmed Exercise

Activity level was monitored through 24-hour activity diaries at sea level. A program of strenuous exercise, including cycle ergometry, treadmill walking, and weight

lifting was devised for each subject to be undertaken at altitude. The program at altitude mimicked as much as possible the sea-level activities and served to prevent detraining as well as to balance energy expenditure under the two environmental conditions.

Body Composition

Body weight was measured each morning throughout the study. A waist circumference measurement was obtained during the sea-level baseline phase and on days 3 and 21 during the dietary phases at sea level and altitude. The body weight and circumference measurements were used in an equation (32) to estimate changes in lean body mass, fat mass, and percentage fat. Total body water was estimated using whole body tetrapolar bioelectrical impedance as previously described (11;22). Impedance measures were obtained during the sea-level baseline phase and on days 1, 3 and 21 during the dietary phases at sea level and at altitude. Previous work from our laboratory (10;11) indicated that these equations provide an accurate means of assessing body composition and total body water changes associated with weight loss and altitude exposure.

Physical Performance Task Selection

A sizeable fraction of mild body weight loss at altitude is often attributed to a small loss of lean body mass (25). (3;20) A further reduction in lean body mass attributable to a very large energy deficit would be expected to have a deleterious effect on strength and endurance performance. However, it was also appreciated that loss of body fat could improve the power to weight ratio and improve physical performance on tasks requiring body movement against gravity. Thus, for such reasons, factors were considered in selecting tasks appropriate to provide an accurate portrayal of the effect of energy deficit on physical performance. Some of these factors included: subject safety, subject willingness to perform the task on multiple occasions, sensitivity to body weight and lean body mass loss, military relevance, minimal complexity (i.e., no requirement of a high skill level), reproducibility, validity, assessment of aerobic fitness versus strength, size of active muscle mass utilized, scheduling (e.g., short task duration to minimize interference with other substudies), energy source (i.e., aerobic, anaerobic), central circulatory versus peripheral limitations to exercise, and measurement objectivity and criteria.

After such factors were considered collectively, four well defined, quantifiable, and independent measures of physical performance were selected. These were:

1. Maximal Oxygen Uptake.

An incremental progressive exercise bout to volitional exhaustion on a bicycle ergometer was used to assess maximal, whole-body aerobic exercise performance. Following resting measurements, subjects began pedaling at 70 rpm at 50 watts for a 5-minute warm-up. The power output was then increased stepwise every 2 minutes until O_2 uptake failed to increase or the subject stopped the test. A three-lead electrocardiogram was used to monitor heart rate, and expired air was analyzed for

respiratory volumes and oxygen uptake. Maximal oxygen uptake for all subjects was determined during the sea-level body weight stabilization phase and on days 2 and 20 of the dietary phase.

2. "Shell Loading" Task.

To determine the impact of energy deficit on heavy, body weight-bearing work performance, a military relevant occupational task involving lifting and carrying was chosen. For this task, the subjects had to lift from a 76 cm high platform a 91 cm long, 25 kg dummy 105 mm shell and carry it 8 m and then place it on a 132 cm high platform. Each subject had to accomplish 50 complete repetitions as quickly as possible. The performance outcome was time to complete all repetitions. All subjects performed this task at least once during the sea-level body weight stabilization phase and on days 3, 11, and 21 of the dietary phase.

3. Elbow Flexion Weight Lifting Task.

This task was chosen to assess the impact of energy deficit on physical performance during repetitive submaximal contractions to exhaustion. For this task, the subjects used a dumbbell to perform full-range, one-arm elbow flexions ("curls") to exhaustion while seated on a bench with their back resting and stabilized against a 45-degree incline. Throughout the entire movement, the hand was positioned midway between full supination and pronation such that the thumb was facing up. All repetitions were performed with the left arm at the rate of 22 curls•min^{-1}, paced by a traditional-style metronome. The subjects had visual contact with the metronome and had to match the movement (i.e., contraction and extension) of their arm to the back and forth movement of the pendulum. Subjects were not allowed to swing their arm at the bottom of the movement or drop their arm from the fully contracted position. The weight chosen was previously selected via early familiarization sessions such that each subject could perform approximately 25 to 35 repetitions during the sea-level baseline phase. "Exhaustion" occurred when the subject could not maintain the repetition pace using only correct form. The weight of the dumbbell used varied among subjects; but was constant for each subject throughout the study (approximately 9 to 10% of baseline body weight). All subjects performed this task during the sea-level body weight stabilization phase and on days 2, 10, and 20 of the dietary phase.

4. Adductor Pollicis Muscle Fatigue Task.

Muscle fatigue experiments were performed using a device that permitted static contractions isolated to the adductor pollicis muscle ("thumb muscle"). The right hand and arm of the subject were secured in supination with the fingers flexed and thumb abducted as previously described (9;14). A force transducer was attached by an unexpandable link to a strap looped around the interphalangeal joint of the right thumb. The force transducer was interfaced with an amplifier, chart recorder, and oscilloscope. Subjects had visual contact with the oscilloscope tracings at all times to provide them with feedback for maintaining the correct force during submaximal contractions.

After the subject was seated, and the hand and thumb properly oriented and secured, three to five, five-sec baseline maximal voluntary contractions (MVC) were

performed, with a one-min rest between each MVC. For each subject, during the body weight stabilization phase at sea level, the highest MVC force attained was used to set the absolute target force of submaximal contractions that was used throughout the rest of the study (i.e., during the body weight stabilization phase and days 2, 10, and 20 of the dietary phase).

For the sea-level body weight stabilization phase, submaximal exercise consisted of intermittent, 5-sec static muscle contractions at a target force of 50% of rested MVC force followed by 5-sec rest. At the end of every min (i.e., every sixth contraction), a MVC was performed for 5 full sec instead of the 50% MVC force contraction. An investigator timing the events verbally instructed the subjects to start and stop each submaximal and maximal contraction. Subjects were required to increase muscle force as rapidly as possible to the maximal or target level, respectively. When the target force could not be maintained for 5 sec or MVC force fell to or below target force, the subjects were considered exhausted and were instructed to stop the submaximal contractions. A MVC was performed immediately upon reaching exhaustion and at the end of each min for 5 min of recovery. The adductor pollicis muscle fatigue task therefore provided precise quantifiable measures of small muscle strength, endurance and recovery during each exercise bout.

Statistics

A two-factor (days X group) analysis of variance with repeated measures on one factor (days) were utilized for nearly all body composition and physical performance comparisons. Post hoc analyses (Tukey) were performed when appropriate. Statistical significance was accepted when $P < 0.05$.

RESULTS

BODY COMPOSITION

The age, body weights, heights, percentage body fat and body mass index of the subjects on day 5 of their respective 7-day weight maintenance phase at sea level are presented in Table 1. There were no differences in age, height, and body mass index among groups. Body weight of the subjects in the ADQ group was lower than the body weight of the subjects in the HYPO and DEF groups. In addition, the subjects in the DEF and ADQ groups began the study leaner than the subjects in the HYPO group.

TABLE 1. Age, Body Weight and Height, %Body Fat, and Body Mass Index for the Three Experimental Groups During Sea-Level Baseline

Group:	Age (yrs)	Weight (kg)	Height (cm)	Body Fat (%)	BMI (BW/(Ht)^2)
HYPO (n=9)	23.1 ± 6	78.9 ± 6	176.9 ± 8	15.2 ± 5	25.3 ± 2
DEF (n=10)	22.6 ± 4	80.4 ± 12	178.9 ± 6	11.5 ± 4^a	25.0 ± 2
ADQ (n=7)	21.1 ± 3	74.4 ± 7^{a,b}	176.1 ± 5	10.7 ± 4^a	24.0 ± 2

Values are means ± SD; BMI = Body Mass Index (kg/m^2); ^{a}P < 0.01 from HYPO group; ^{b}P<0.01 from DEF group.

Tables 2a and 2b present the body weights for the groups during the SL baseline phase and on days 3 and 21 of the dietary phases. Table 2a shows that the HYPO and DEF groups lost body weight during the dietary phase while the ADQ group maintained body weight. By day 21, there were no significant differences in body weight among groups. Table 2b shows that while the HYPO and DEF groups lost significant amounts of body weight compared to the SL baseline phase and compared to the ADQ group, the amount and rate (expressed as $g \cdot day^{-1}$) of body weight loss was significantly greater for the DEF group than for the HYPO group. Table 2b also indicates that the rate of body weight loss for all groups in the first three days of the dietary phase was at least two-fold faster than during the entire 21-day dietary phase.

TABLE 2a. Body Weight (kg) during Sea-Level Baseline, and on Days 3 and 21 of the Dietary Phase

Group:	SL Baseline	Day 3	Day 21
HYPO (n=9)	78.9 ± 6	77.8 ± 6	75.0 ± $6^{*,\#}$
DEF (n=10)	80.4 ± 12	77.8 ± 10	73.8 ± $9^{*,\#}$
ADQ (n=7)	74.4 ± $7^{a,b}$	74.1 ± $7^{a,b}$	73.4 ± 7

Values are means ± SD; *P < 0.01 from SL Baseline; #P < 0.01 from Day 3; [a]P < 0.01 from HYPO group; [b]P<0.01 from DEF group

TABLE 2b. Absolute (kg) and Rate ($g \cdot day^{-1}$) of Body Weight Loss During the Dietary Phase Relative to Sea-Level Baseline

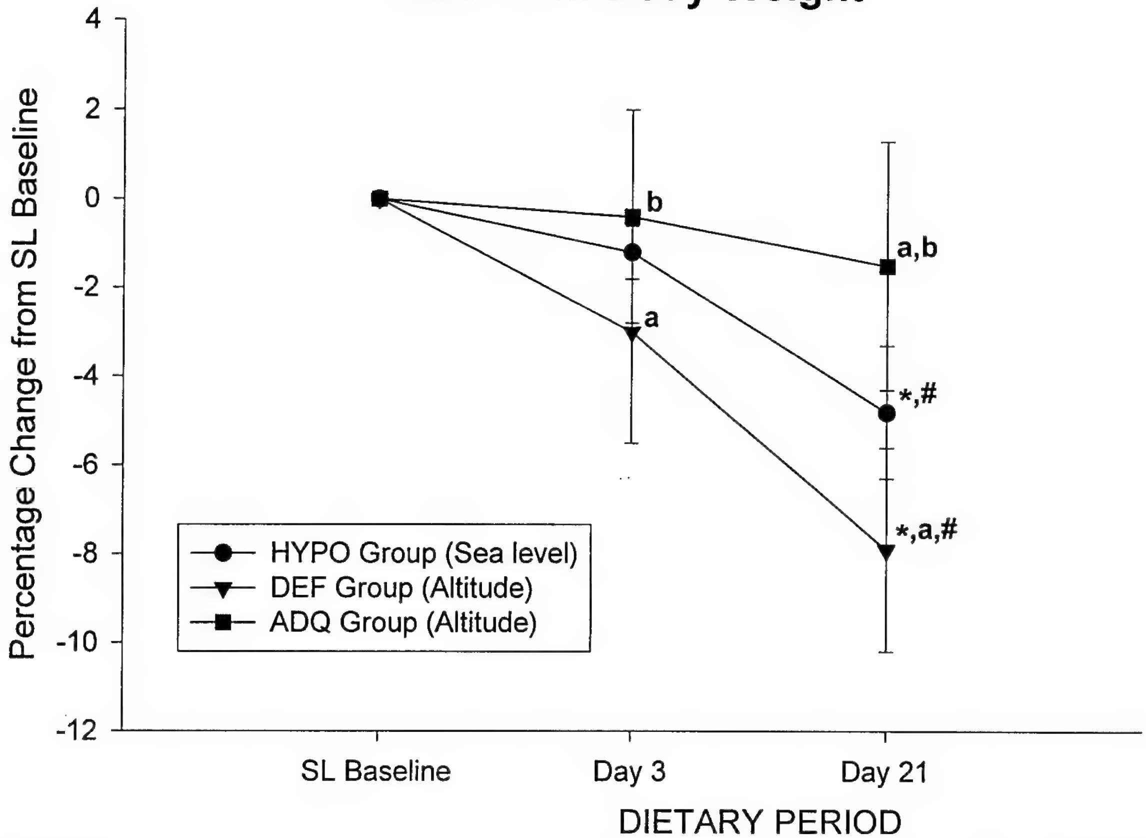
Group:	Day 3	Day 21
HYPO (n=9)	-1.0 ± 0.6 (- 329 $g \cdot day^{-1}$)	- 3.8 ± $1.3^{\#}$ (-180 $g \cdot day^{-1}$)
DEF (n=10)	-2.6 ± 2.3^{a} (- 863 $g \cdot day^{-1}$)	- 6.6 ± $2.7^{a,\#}$ (- 312 $g \cdot day^{-1}$)
ADQ (n=7)	-0.3 ± 1.7^{b} (-102 $g \cdot day^{-1}$)	-1.1 ± $1.9^{a,b}$ (- 50 $g \cdot day^{-1}$)

Values are means ± SD; [a]P < 0.01 from HYPO group; [b]P<0.01 from DEF group; #P < 0.01 from Day 3.

Figure 2 illustrates the percentage of weight loss for the three groups normalized to their SL baseline phase value. While both the HYPO and DEF groups lost a significant percentage of their body weight by the 21st day of the dietary phase, the percentage weight loss of the DEF group (-7.9 ± 2.3%) was approximately two-fold greater than that of the HYPO group (-4.8 ± 1.5%)[1]. The ADQ group maintained SL baseline body weight throughout the altitude exposure.

[1] One reason for the much greater body weight loss of the DEF compared to the HYPO group became apparent on closer inspection of the individual dietary and weight loss data of the two groups (data to be presented in a future report). In general, subjects in the HYPO group were not as faithful to their hypocaloric diets during the 21-day dietary phase as compared to the subjects in the DEF group. The relative noncompliance was likely a consequence of the HYPO group subjects living at their homes and being unsupervised compared to the DEF group subjects who lived at Pikes Peak were under close supervision.

FIGURE 2: Body Weight



*P<0.01 from Sea-Level Baseline; [a]P<0.01 from HYPO Group; [b]P<0.01 from DEF Group; [#]P<0.01 from Day 3

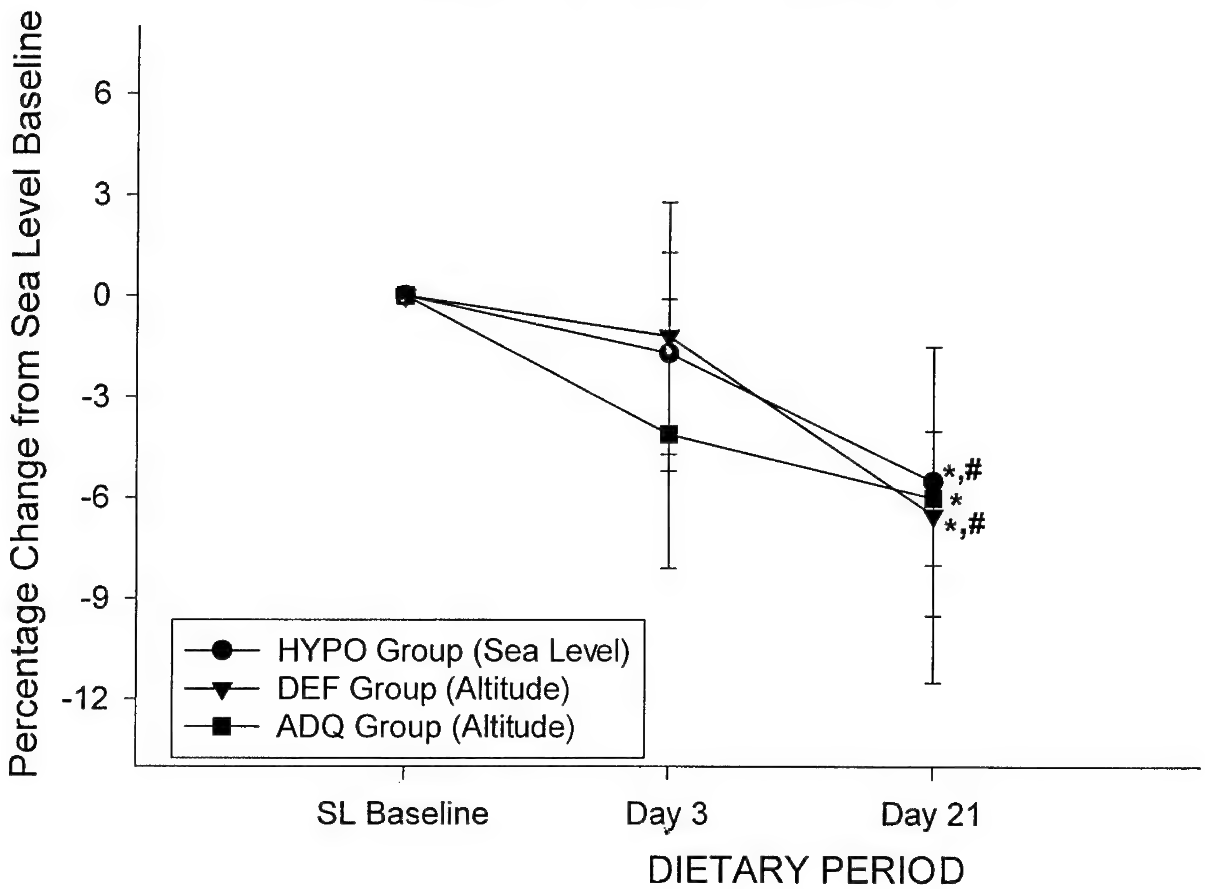
Table 3 presents the total body water values calculated throughout the study and indicates that total body water declined from SL baseline values in all three groups by day 21 of each dietary phase. As indicated in Figure 3, there were no significant differences in total body water loss among groups; but the total body water loss was greater on day 21 than for day 3 for the HYPO and DEF groups.

TABLE 3. Total Body Water (liters) During Sea-Level Baseline, and on Days 1, 3 and 21 of the Dietary Phase

Group:	SL Baseline	Day 1	Day 3	Day 21
HYPO (n=8)[+]	38.0 ± 4	n/m	37.3 ± 3	35.8 ± 3[#,*]
DEF (n=9)[++]	40.5 ± 5	39.9 ± 4	40.0 ± 4	37.8 ± 4[#,*]
ADQ (n=6)[++]	38.5 ± 3	36.4 ± 3	36.8 ± 2	36.2 ± 3*

Values are means ± SD; n/m = not measured; [+]Day 21 data for one subject not collected, [++]SL baseline data for one subject not collected. *P < 0.01 from SL baseline. [#]P < 0.01 from day 3

FIGURE 3: Total Body Water



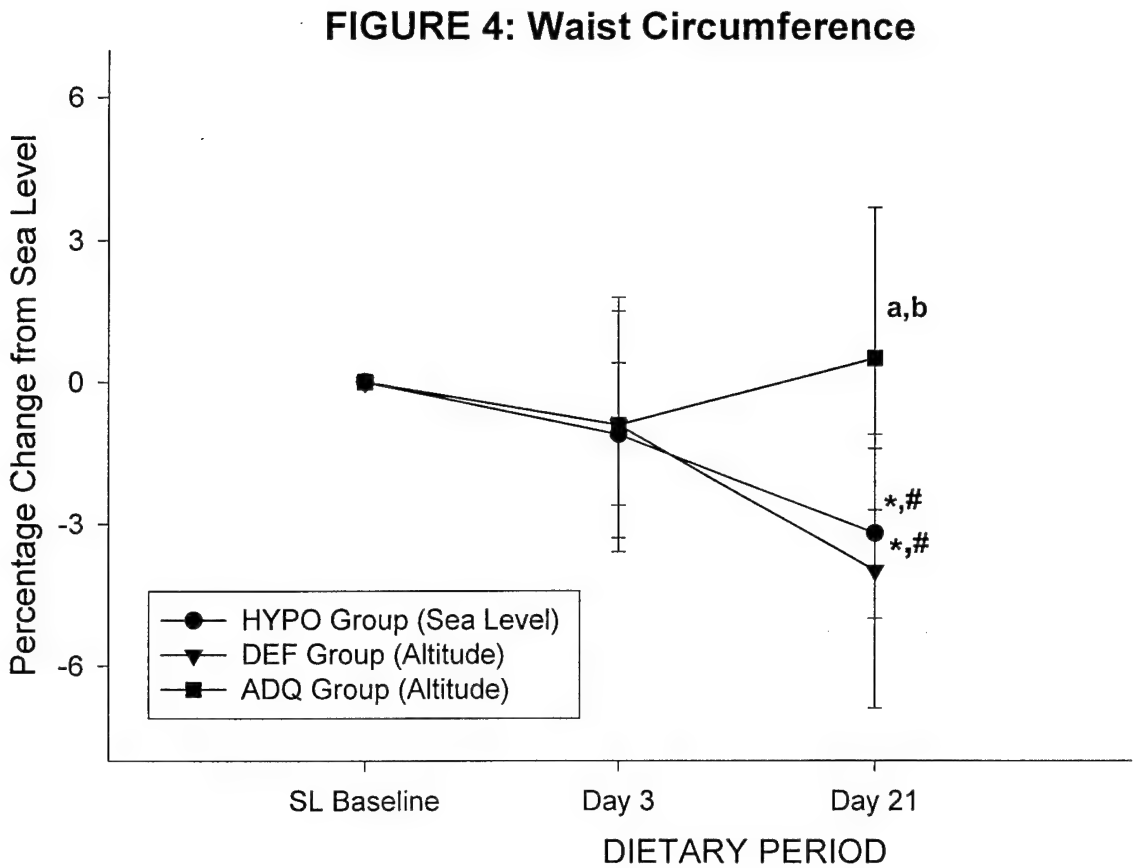
*P<0.01 from Sea-Level Baseline; #P<0.01 from Day 3

Table 4 presents the waist circumference measurements for the three groups throughout the study. Waist circumferences of the DEF and the ADQ groups were less than that of the HYPO group during the SL baseline phase and the differences were maintained throughout the study. Table 4 and Figure 4 show that waist circumference declined in the HYPO and DEF groups during the dietary phase while there was no decline in the ADQ group. Moreover, Figure 4 shows that waist circumference was similar among groups on day 3 and did not differ from SL baseline but was significantly greater on day 21 of the dietary phase for the HYPO and DEF groups compared to the ADQ group.

TABLE 4. Waist Circumfererence (cm) During Sea-Level Baseline, and on Days 3 and 21 of the Dietary Phase

Group:	SL Baseline	Day 3	Day 21
HYPO	83.7 ± 6	82.7 ± 5	81.1 ± 6*
DEF	80.0 ± 7[a]	79.2 ± 7[a]	76.7 ± 6*,[a]
ADQ	77.8 ± 5[a,b]	78.4 ± 5[a]	78.1 ± 5[a]

Values are means ± SD; *P < 0.01 from SL Baseline; [a]P < 0.01 from HYPO group; [b]P<0.01 from DEF group



*P<0.01 from Sea-Level Baseline; [a]P<0.01 from HYPO group; [b]P<0.01 from DEF group; [#]P<0.01 from Day 3

Table 5 shows the calculated values for lean body mass for the three groups throughout the study. During the SL baseline phase, lean body mass of the DEF group was greater than that of the HYPO and ADQ groups. During the 21-day dietary phase, the HYPO and DEF groups lost lean body mass while the lean body mass of the ADQ group remained relatively stable. By day 21, there was no significant difference among groups.

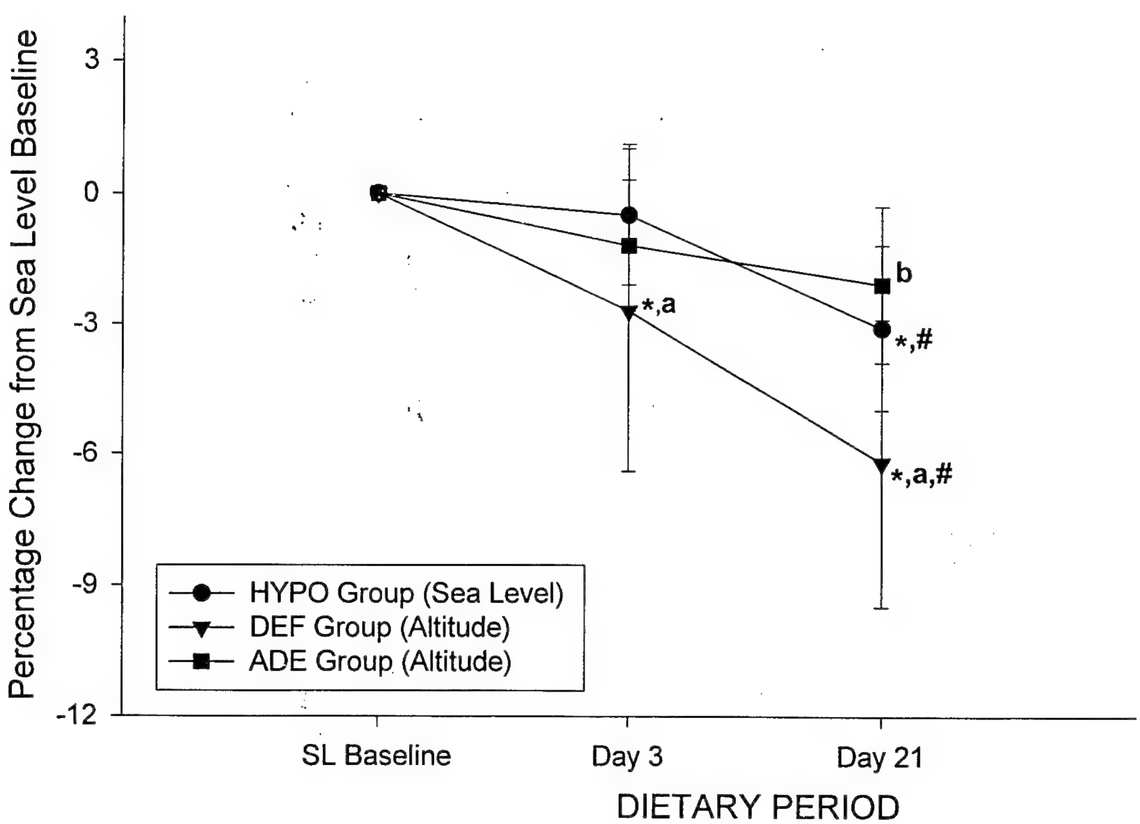
TABLE 5. Lean Body Mass (kg) During Sea-Level Baseline, and on Days 3 and 21 of the Dietary Phase

Group:	SL Baseline	Day 3	Day 21
HYPO	66.8 ± 6	66.5 ± 6	64.7 ± 6*
DEF	71.0 ± 10[a]	68.8 ± 7*,[a]	66.4 ± 7*,[#]
ADQ	66.3 ± 5[b]	65.5 ± 5[b]	64.9 ± 5

Values are means ± SD; *P < 0.01 from SL Baseline; [#]P < 0.01 from Day 3; [a]P < 0.01 from HYPO group; [b]P<0.01 from DEF group.

Figure 5 illustrates that by day 3, the DEF group had a significantly greater percentage reduction in lean body mass than either the ADE or HYPO group. By day 21, both the HYPO and DEF groups had significant percentage reductions from day 3 in lean body weight with the percentage reduction for the DEF group (-6.2 ± 3%) being twice as great as that for the HYPO group (-3.1 ± 2%). The percentage change in lean body mass for the ADE group (-2.1 ± 2%) was significantly less than that for the DEF group and was not significantly different from the HYPO group.

FIGURE 5: Lean Body Mass



*P<0.01 from Sea-Level Baseline; [a]P<0.01 from HYPO Group; [b]P<0.01 from DEF Group; [#]P<0.01 from Day 3

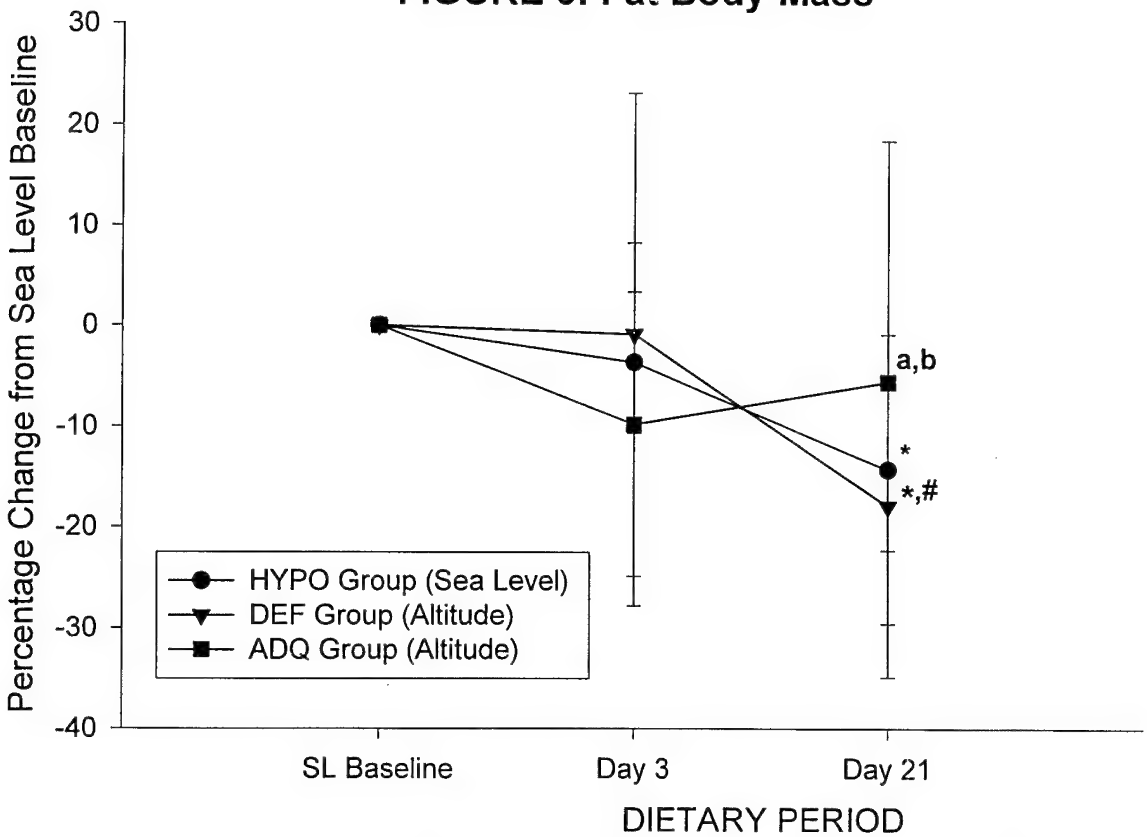
Table 6 shows the values for fat body mass for the groups throughout the study. During the SL baseline phase, the fat body mass of the HYPO group was greater than the DEF and ADQ groups but there was no difference between the DEF and ADQ groups. During the dietary phase, the HYPO and DEF groups lost fat body mass while fat body mass of the ADQ group remained stable, relative to the SL baseline phase. Moreover, fat body mass in the DEF group was lower on day 21 than on day 3. Figure 6 illustrates that the percentage of fat body mass loss in the dietary phase for the HYPO and DEF groups was significantly greater than that of the ADE group after 21 days.

TABLE 6. Fat Body Mass (kg) During Sea-Level Baseline, and on Days 3 and 21 of the Dietary Phase

Group:	SL Baseline	Day 3	Day 21
HYPO	12.0 ± 4	11.3 ± 3	10.3 ± 4*
DEF	9.4 ± 4[a]	9.0 ± 4[a]	7.4 ± 4*,#,a
ADQ	8.1 ± 3[a]	8.6 ± 3[a]	8.4 ± 3[a]

Values are means ± SD; *P < 0.01 from SL Baseline; #P < 0.01 from Day 3; [a]P < 0.01 from HYPO group; [b]P<0.01 from DEF group

FIGURE 6: Fat Body Mass



*P<0.01 from Sea-Level baseline; [a]P<0.01 from HYPO group; [b]P<0.01 from DEF Group; #P<0.01 from Day 3

Table 7 provides a summary of the absolute changes in body weight and body composition after 21 days of dietary control under three distinct conditions: energy deficit at sea level (i.e., HYPO group), energy deficit at altitude (i.e., DEF group) and adequate energy to maintain body weight while at altitude (i.e.,ADQ group). The data indicate that despite the DEF group losing nearly twice as much body weight as the HYPO group, both groups lost nearly identical amounts of fat body mass. The data also indicate that the lean body mass loss of the HYPO group (-2.1 kg) was accounted for entirely by total body water (-2.2 L). It is interesting also that all three groups lost nearly an identical volume of total body water despite a large difference in body weight loss and in environmental exposure.

TABLE 7. Summary of Absolute Changes in Body Weight, Lean Body Weight, Fat Body Weight, and Total Body Water from Sea-Level Baseline to Day 21 of the Dietary Phase

GROUP:	Body Weight (kg)	Lean Body Mass (kg)	Fat Body Mass (kg)	Total Body Water (liters)
Hypocaloric	- 3.8 ± 1	- 2.1 ± 1	- 1.7 ± 1	- 2.2 ± 2
Deficit	- 6.6 ± 3	- 4.6 ± 3	- 2.0 ± 1	- 2.8 ± 2
Adequate	- 1.1 ± 2	- 1.4 ± 1	+ 0.3 ± 2	- 2.3 ± 1

Values are means ± SD; Values in table reflect only subjects in which complete data were collected on all parameters listed. Thus, the numbers of subjects in the HYPO, DEF, and ADQ group are 8, 9, and 6, respectively.

EXERCISE PERFORMANCE

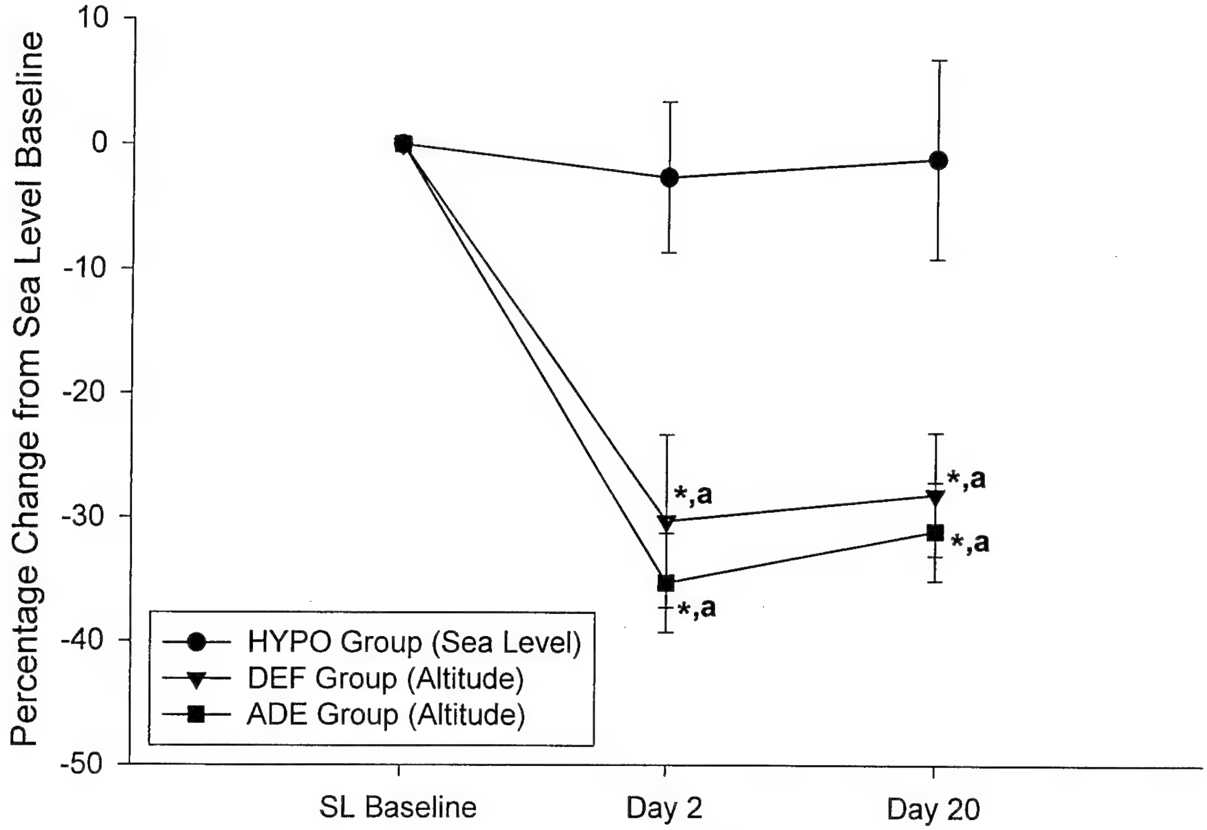
Table 8a shows that $\dot{V}O_2max$ --- expressed in units of ml•min^{-1} --- measured during the SL baseline phase for both the DEF and ADQ groups was higher than that of the HYPO group. Throughout the dietary phase, $\dot{V}O_2max$ for the HYPO did not differ significantly from the SL baseline phase. Table 8a and Figure 7 show that for both the DEF and ADQ groups, $\dot{V}O_2max$ was significantly reduced during the dietary phase at altitude by approximately 30 to 32%when compared to SL baseline. Maximal oxygen uptake was therefore affected by altitude exposure but not weight loss.

TABLE 8a. Maximal Oxygen Uptake (ml•min^{-1}) During Sea-Level Baseline and on Days 2 and 20 of the Dietary Phase

Group:	SL Baseline	Day 2	Day 20
HYPO	3545 ± 544	3452 ± 558	3488 ± 471
DEF	4151 ± 446^{a}	2889 ± 358^{*,a}	2986 ± 376^{*,a}
ADQ	3909 ± 482^{a}	2530 ± 346^{*,a,b}	2689 ± 335^{*,a,b}

Values are means ± SD; *P < 0.01 from SL Baseline; ^{a}P < 0.01 from HYPO group; ^{b}P<0.01 from DEF group

FIGURE 7: Maximal Oxygen Uptake ($ml \cdot min^{-1}$)



*$P<0.01$ from Sea-Level Baseline; [a]$P<0.01$ from HYPO Group

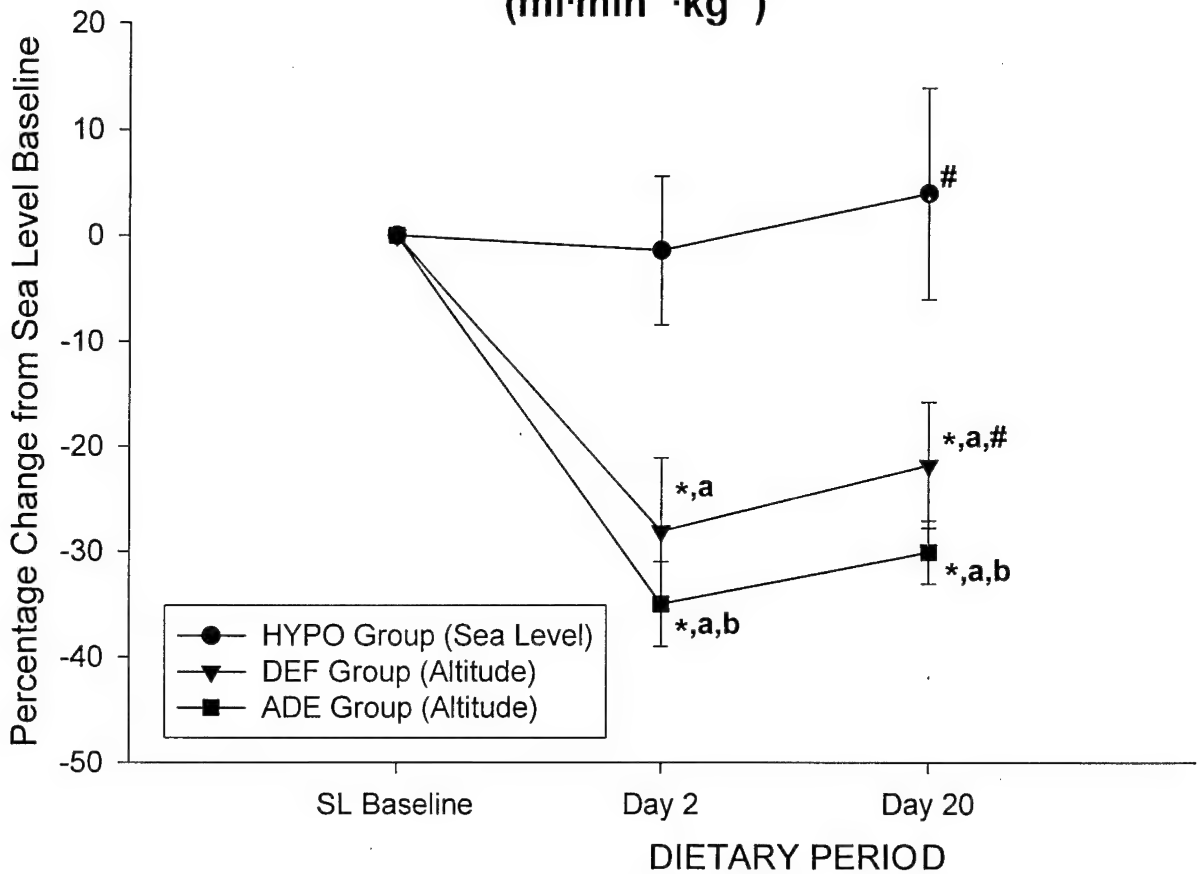
Table 8b shows that $\dot{V}O_2max$ --- expressed in units of $ml \cdot min^{-1} \cdot kg^{-1}$ --- measured during the SL baseline phase for both the DEF and ADQ groups were higher than that of the HYPO group. The DEF and ADQ groups, however, were remarkably similar at SL baseline. There was little change in $\dot{V}O_2max$ from SL baseline to day 2 of the dietary phase for the HYPO group (Figure 8). However, by day 20 of the dietary phase, $\dot{V}O_2max$ for the HYPO was significantly higher from SL baseline, attributable directly to the body weight loss. Maximal oxygen uptake for the DEF and ADQ groups declined significantly from SL baseline on day 2 of altitude exposure, and the decline was greater for the ADQ group than for the DEF group. By day 20, $\dot{V}O_2max$ for the DEF group was significantly increased compared to day 2, but still more than 20% reduced from SL baseline. The slight improvement at altitude was directly attributable to body weight loss. Maximal oxygen uptake for the ADE group did not significantly increase from day 2 to day 20 of the dietary phase at altitude.

TABLE 8b. Maximal Oxygen Uptake ($ml \cdot min^{-1} \cdot kg^{-1}$) During Sea-Level Baseline and on Days 2 and 20 of the Dietary Phase

Group:	SL Baseline	Day 2	Day 20
HYPO	45.2 ± 7	44.5 ± 7	46.7 ± 7*
DEF	52.2 ± 6[a]	37.3 ± 4*,a	40.6 ± 4*,#,a
ADQ	52.6 ± 5[a]	34.1 ± 3*,a	36.8 ± 4*,a,b

Values are means ± SD; *P < 0.01 from SL Baseline; #P < 0.05 from Day 2; [a]P < 0.01 from HYPO group; [b]P<0.01 from DEF group

FIGURE 8: Maximal Oxygen Uptake ($ml \cdot min^{-1} \cdot kg^{-1}$)



*P<0.01 from SL Baseline; [a]P<0.01 from HYPO Group; [b]P<0.01 from DEF Group; #P<0.01 from Day 2

Table 8c shows that $\dot{V}O_2max$ --- expressed in units of $ml \cdot min^{-1} \cdot kg\ LBM^{-1}$ --- measured during the SL baseline phase for both the DEF and ADQ groups were higher than that of the HYPO group. The DEF and ADQ groups, however, were remarkably similar at SL baseline. There was little change in $\dot{V}O_2max$ from SL baseline to days 2 and 20 of the dietary phase for the HYPO group. Maximal oxygen uptake for the DEF and ADQ groups declined significantly (P<0.01) from SL baseline on day 2 of altitude exposure, and the decline was greater for the ADQ group (-53%) than for the DEF

group (-41%, P <0.05). Compared to day 2, $\dot{V}O_2max$ on day 20 tended to be higher (P>0.05) for both groups, with the improvement being very similar for both groups. This finding indicates that the large loss of LBM in the DEF group (and the HYPO group at sea level) did not impair maximal performance at altitude (or sea level).

TABLE 8c. Maximal Oxygen Uptake (ml•min^{-1} •kg LBM^{-1}) During Sea-Level Baseline and on Days 2 and 20 of the Dietary Phase

Group:	SL Baseline	Day 2	Day 20
HYPO	53.1 ± 7	51.9 ± 7	54.0 ± 7
DEF	59.0 ± 7^{a}	42.2 ± 5^{*,a}	45.1 ± 4^{*,a}
ADQ	59.0 ± 6^{a}	38.6 ± 4^{*,a}	41.5 ± 5^{*,a}

Values are means ± SD; *P < 0.01 from SL Baseline; ^{a}P < 0.01 from HYPO group;

The times to complete the shell-loading task are presented in Table 9. During the SL baseline phase, times to complete the task for the DEF and ADQ were similar, and also were significantly less than for the HYPO group. During the dietary phase, times for the HYPO group progressively improved and were significantly different from SL baseline on days 11 and 21. Interestingly, performance of the shell-loading task for the HYPO group improved to such a degree that by day 21, performance time was virtually identical to the DEF and ADQ groups measured during the SL baseline phase.

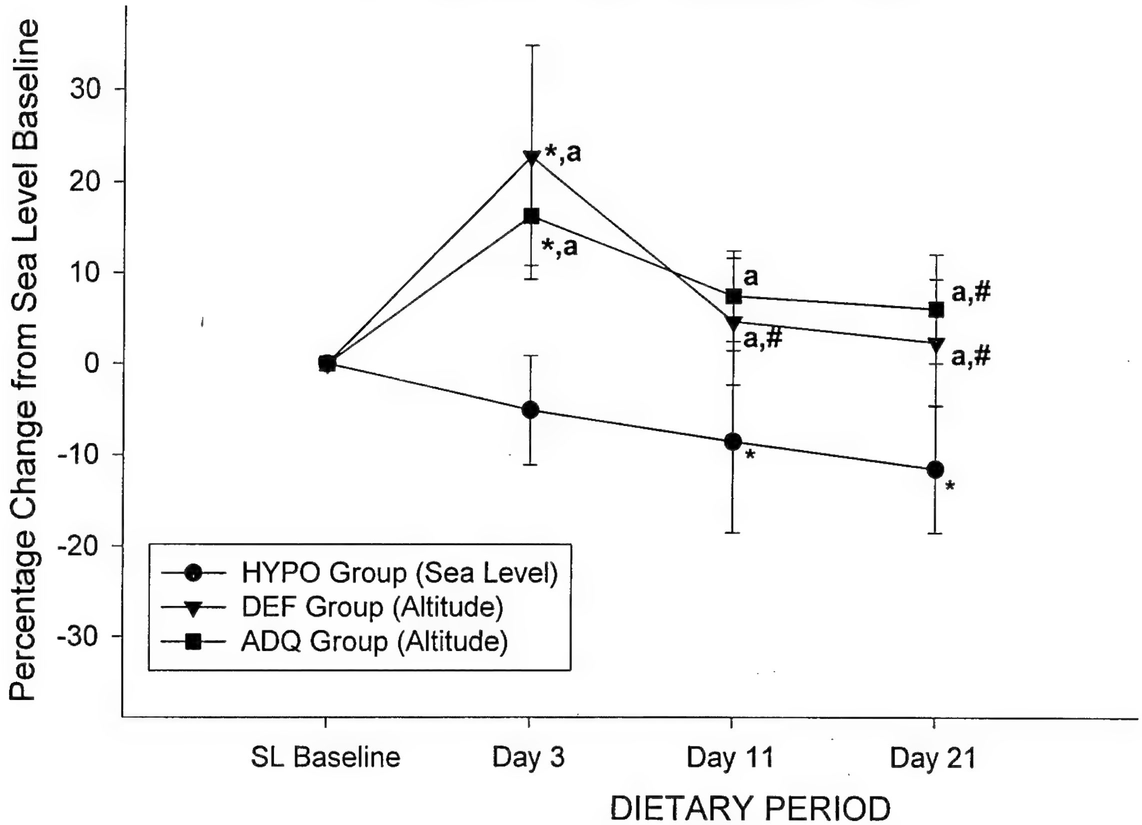
With altitude exposure, times for the DEF and ADQ groups were initially increased (i.e., worsened) by approximately 20% compared to the sea-level baseline phase (Figure 9) but then gradually decreased (i.e., improved) on days 11 and 21 to times that did not differ significantly from their respective SL baseline values. Figure 9 also illustrates that the times for the DEF and ADQ groups during their entire stay at altitude were always approximately 15 to 25% greater than the HYPO group on any given day during the dietary phase.

TABLE 9. Shell Loading Times (min:sec) During Sea-Level Baseline and on Days 3, 11, and 21 of the Dietary Phase

Group:	SL Baseline	Day 3	Day 11	Day 21
HYPO	5:43 ± 0:44	5:25 ± 0:47	5:13 ± 0:52*	5:02 ± 0:37*
DEF	4:54 ± 0:33^{a}	6:01 ± 0:55^{*,a}	5:06 ± 0:26$^{\#}$	4:59 ± 0:20$^{\#}$
ADQ	5:00 ± 0:29^{a}	5:54 ± 0:40*	5:25 ± 0:33	5:19 ± 0:31$^{\#}$

Values are means ± SD; n = 8 for HYPO group; n = 9 for DEF group; n = 7 for ADQ group; *P < 0.05 from SL Baseline; $^{\#}$P < 0.01 from Day 3; ^{a}P < 0.01 from HYPO group.

FIGURE 9: Shell Loading Times



***P<0.01 from Sea-Level Baseline; [a]P<0.01 from HYPO Group; [#]P<0.01 from Day 3**

Table 10 lists the number of one-arm curls performed throughout the study by all groups using approximately the same dumbbell weight. The number of curls performed by all groups was similar throughout the dietary phase compared to their respective SL baseline values (although there was a strong tendency [P>0.05] for a reduced number of repetitions for the HYPO group on day 20 of the dietary phase). The number of repetitions performed by the HYPO group, however, was significantly lower than the other two groups on day 20. Figure 10 illustrates that none of the groups had a significant percentage change in the number of repetitions during the dietary phase compared to their SL baseline phase.

TABLE 10. One-Arm Curls (repetitions•min^{-1}) During Sea-Level Baseline and on Days 2, 10, and 20 of the Dietary Phase

Group:	Wt Used	SL Baseline	Day 2	Day 10	Day 20
HYPO	7.3 ± 1	26 ± 6	25 ± 5	26 ± 10	20 ± 8
DEF	7.6 ± 1	32 ± 7	29 ± 6	29 ± 5	28 ± 7[a]
ADQ	7.4 ± 1	28 ± 3	26 ± 4	25 ± 5	27 ± 7[a]

Values are means ± SD; Wt. Used = Weight of dumbbell (kg); *P < 0.05 from SL Baseline; [a]P < 0.01 from HYPO group

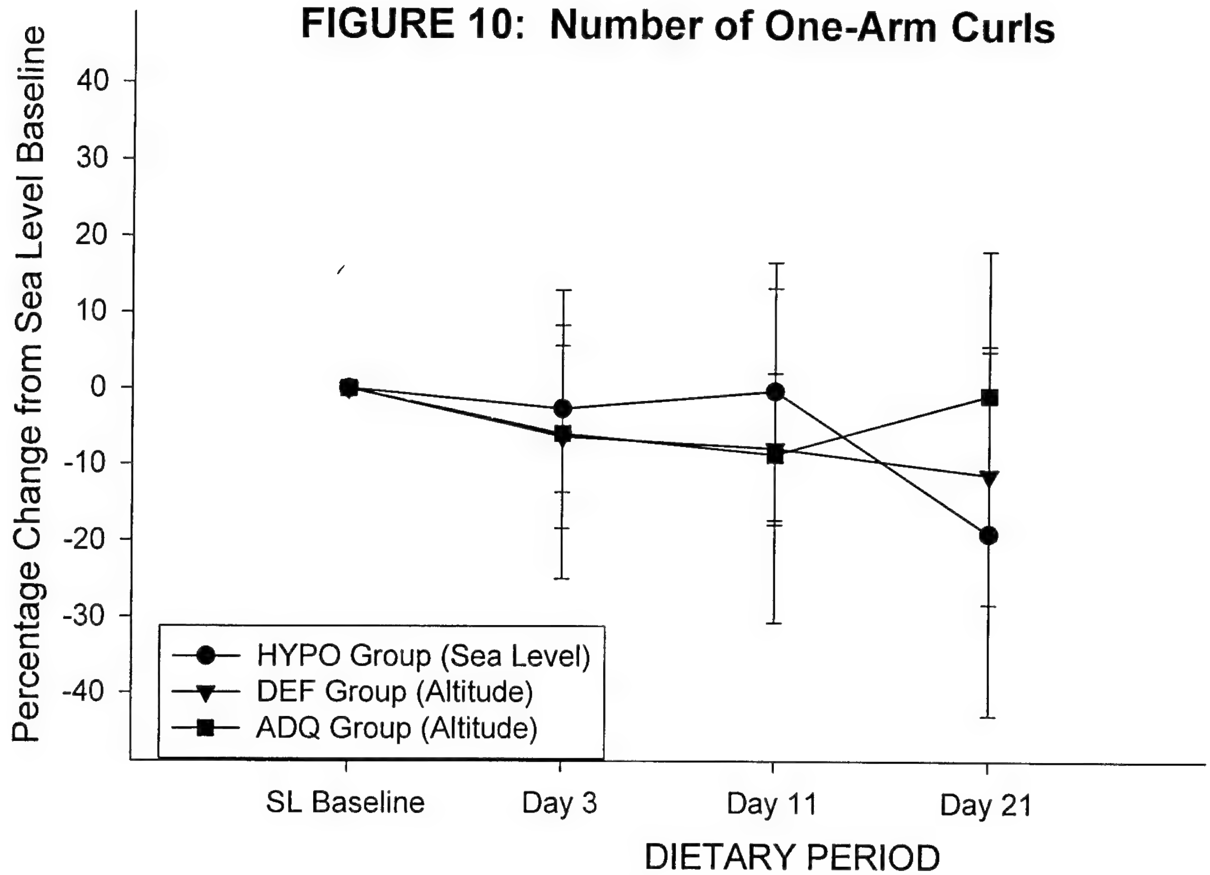


Table 11 shows that maximal voluntary contraction force of the adductor pollicis muscle remained stable for all three groups throughout the study. There were no significant differences within or between groups. Figure 11 also indicates that there were no consistent changes in force from SL baseline throughout the dietary phase.

TABLE 11. Maximal Voluntary Contraction Force (kg) During Adductor Pollicis Muscle Exercise at Sea Level and During Days 2, 10, and 20 of the Dietary Phase

Group:	SL Baseline	Day 2	Day 10	Day 20
HYPO	15 ± 2	15 ± 3	16 ± 2	15 ± 2
DEF	18 ± 3	17 ± 2	16 ± 2	17 ± 2
ADQ	17 ± 3	17 ± 3	17 ± 3	16 ± 3

Values are means ± SD.

FIGURE 11: Maximal Voluntary Contraction Force Adductor Pollicis Exercise

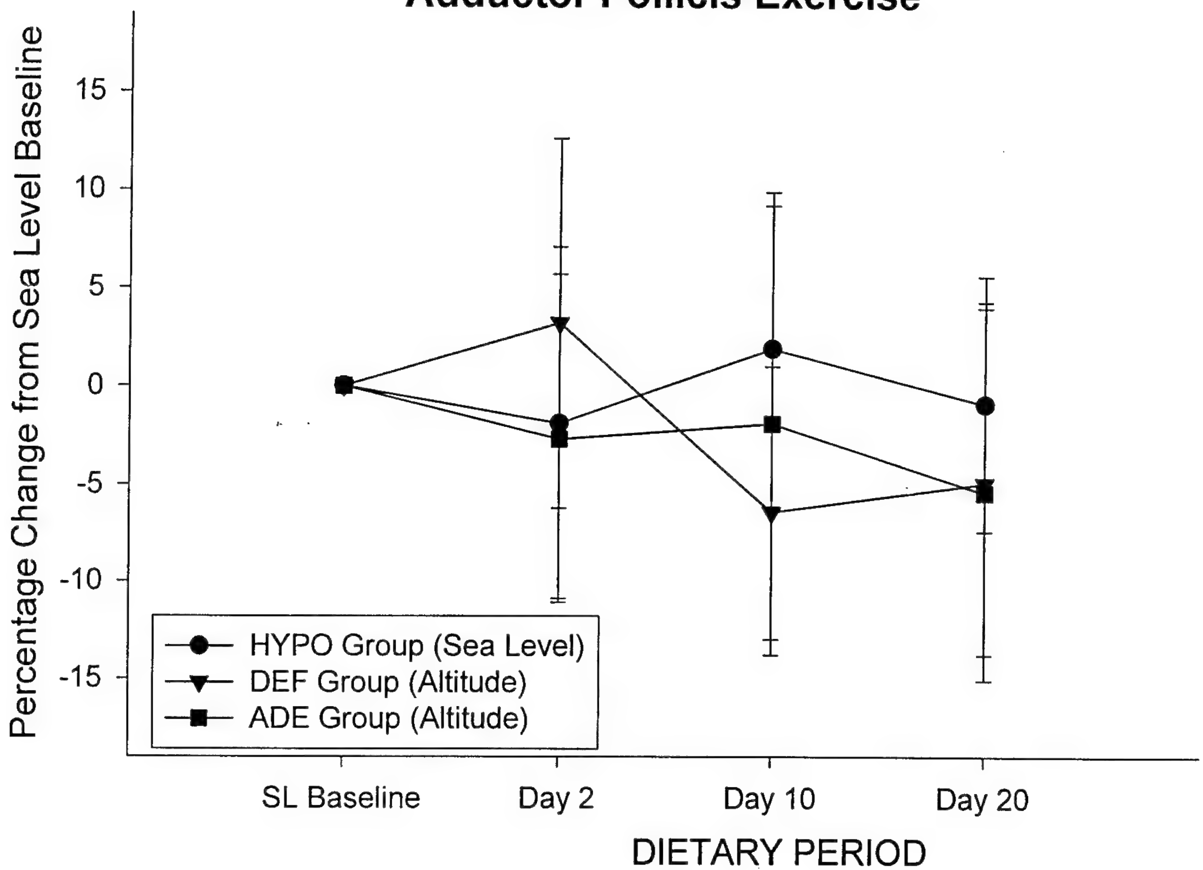


Table 12 and Figure 12 show endurance time to exhaustion during adductor pollicis exercise for all three groups throughout the study. There were no significant differences within or between groups. The times varied considerable within groups (most notably the ADQ group). There were no consistent changes in endurance time from SL baseline throughout the dietary phase.

TABLE 12. Endurance Time to Exhaustion (min:sec) During Adductor Pollicis Muscle Exercise at Sea Level and During Days 2, 10, and 20 of the Dietary Phase

Group:	SL Baseline	Day 2	Day 10	Day 20
HYPO	8:40 ± 5:31	8:40 ± 5:10	9:47 ± 5:44	8:20 ± 6:48
DEF	9:24 ± 3:49	7:12 ± 3:49	8:20 ± 5:23	8:36 ± 4:26
ADQ	8:17 ± 6:48	5:34 ± 2:42	10:43 ± 9:01	7:26 ± 4:39

Values are means ± SD.

FIGURE 12: Endurance Time to Exhaustion Adductor Pollicis Exercise

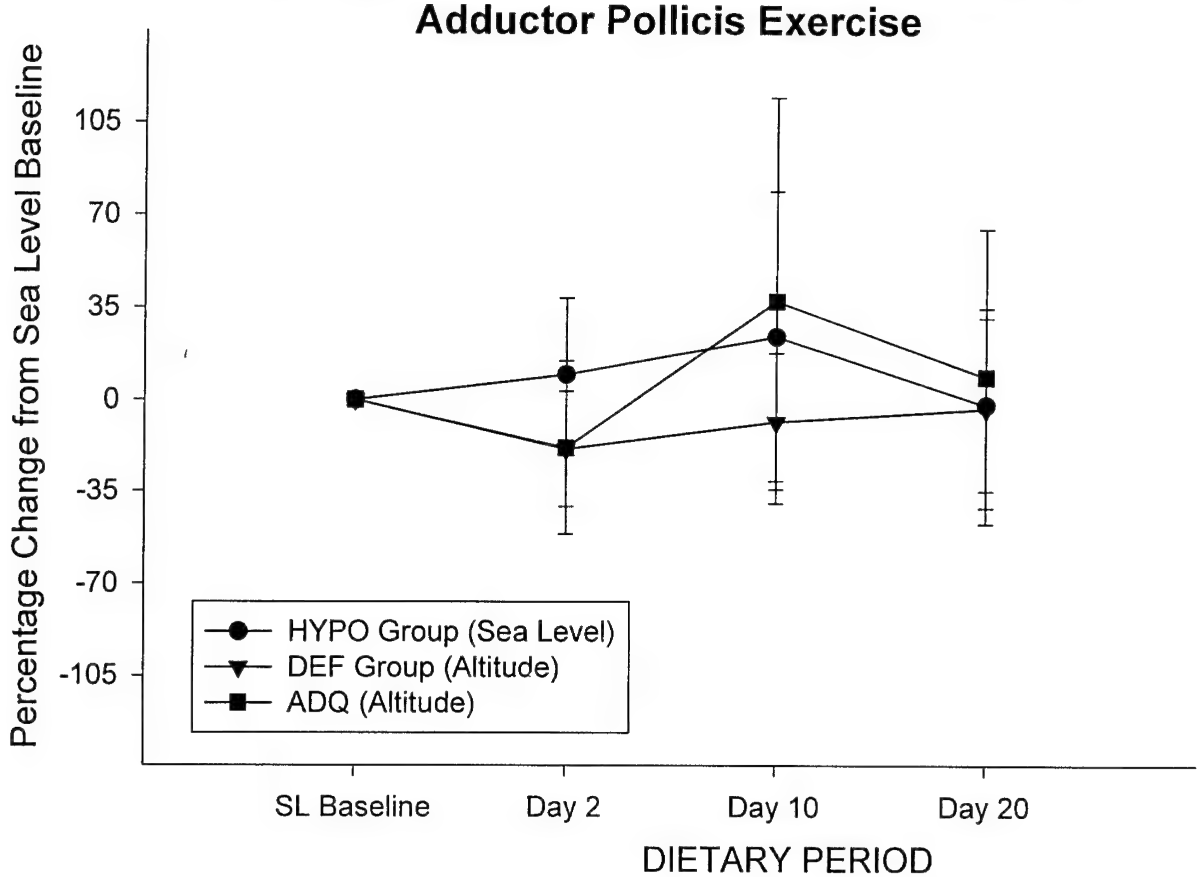


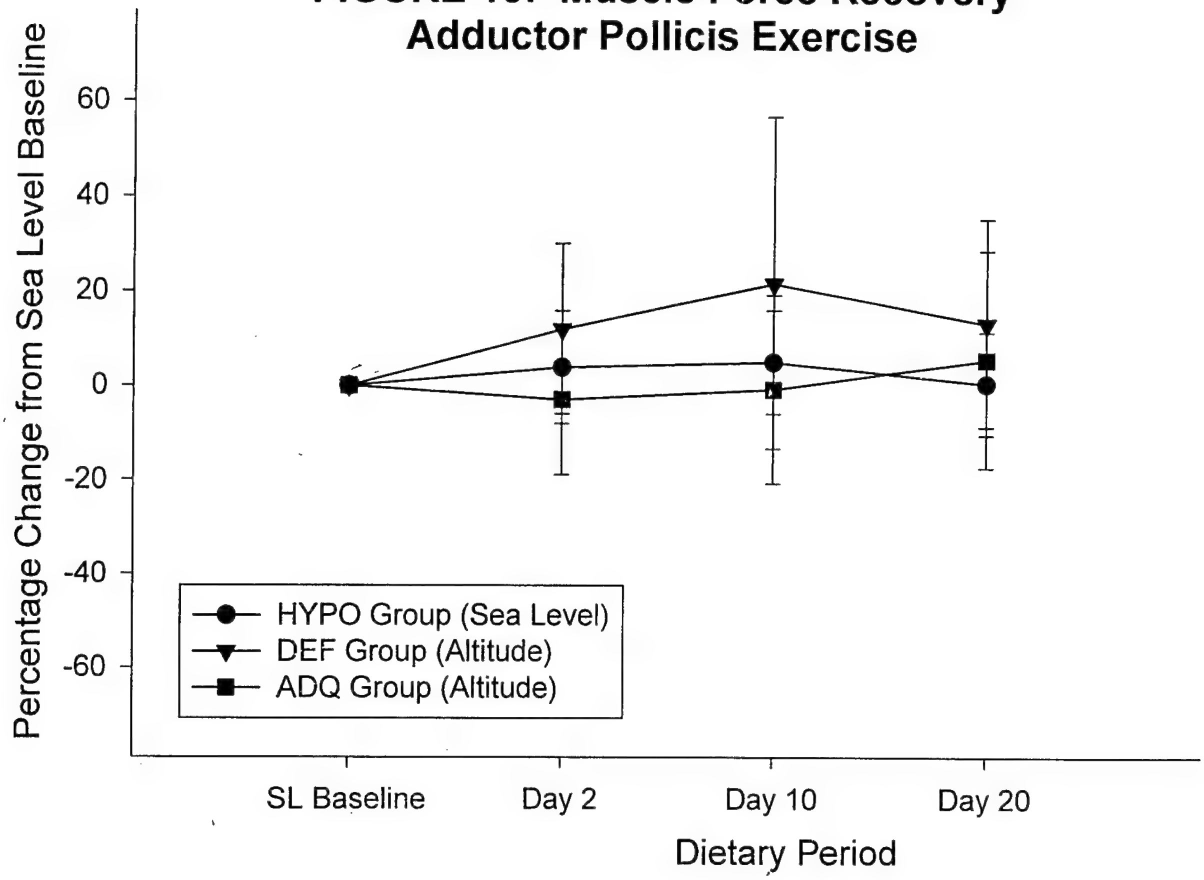
Table 13 shows the force level that the adductor pollicis muscle recovered to after 5 minutes after exhaustive exercise was terminated. (By design, all subjects exercised and became exhausted at 50% rested MVC force). There were no differences between or within groups. Figure 13 indicates also that there was no significant difference in recovery due to altitude exposure or dietary regime as evidenced by comparison to SL baseline. It is interesting, however, that the DEF group tended (P>0.05) to recover to a higher force than the other two groups.

TABLE 13. Adductor Pollicis Muscle Force Recovery (% Rested MVC Force) Five Minutes after Exhaustion

Group:	SL Baseline	Day 2	Day 10	Day 20
HYPO	72.2 ± 7	74.6 ± 8	75.5 ± 8	72.1 ± 7
DEF	67.7 ± 11	74.6 ± 10	79.1 ± 7	74.5 ± 6
ADQ	78.6 ± 14	75.2 ± 11	76.3 ± 10	80.5 ± 5

Values are means ± SD.

FIGURE 13: Muscle Force Recovery Adductor Pollicis Exercise



DISCUSSION

The primary objective of the present study was to determine the effects of large losses in body weight and lean body mass on physical performance during the first three weeks of altitude acclimatization. To that end, ability to perform several well defined, quantifiable, and independent maximal and submaximal exercise and work performance tasks was measured periodically at altitude during severe dietary restriction. Our results clearly indicate that despite an 8% loss in body weight and a 6% loss in lean body mass, physical performance of the dietary restricted group was virtually unaffected and was quite similar relative to a control group that maintained body weight while at altitude. Task performances also did not decline in a third group (tested only at sea level) that had smaller, though significant, losses in body weight and lean body mass.

Much of what was previously known of the physiological and physical performance changes associated with altitude exposure *per se* were based on information collected during research studies from volunteers who resided under comfortable and controlled experimental conditions. In such studies, subjects typically

were offered *ad libitum* a varied menu of numerous items where the quantities of food and fluid were adequate to maintain body weight (4). Yet despite such provisions, subjects lost body weight at an average rate of 100 to 200 g•day^{-1} due primarily to increased diuresis, increased basal metabolic rate, and/or altitude-induced anorexia (2;5;18;21;27). After 21 days of altitude residence at 4300 m, for example, weight losses of approximately 2 to 3 kg (or 2 to 4% body weight for an 80 kg person) were commonly reported (4). These relatively small body weight losses during altitude residence apparently do not impair maximal oxygen uptake ($\dot{V}O_2$max) more than initial altitude exposure without weight loss (13;33). Moreover, there typically is a large improvement in submaximal exercise performance during altitude acclimatization (9;17;23). For such reasons, a small body weight loss at altitude has long been considered an expected and not unfavorable component of the normal altitude acclimatization process (16).

In contrast to research subjects living comfortably in laboratories, military service members can be deployed to, and live under, harsher conditions in mountainous areas and thus are likely confronted with many altitude-related stresses imposed concomitantly. A common finding associated with field operations is a loss of body weight that is much greater than that measured during research studies of similar time periods (1). The additional body weight loss has been attributed to either a greatly reduced caloric intake due to limited availability, variety or palatability of food (often in ration form); to greatly increased energy expenditure; or some combination of both. During field operations in mountainous areas typical daily caloric intake had been only 52% to 64% of energy expended (6;19;24). At such daily deficits, a soldier weighing 80 kg would be expected to lose in 21 days approximately 7 kg or 9% of initial body weight. These estimated values closely agree with the 6.6 kg or 8.2% loss of body weight actually measured in the present study after 21 days of altitude exposure while ingesting 60% of daily energy requirement to maintain body weight.

Prior to the conduct of the present study, the effects on physical performance of such a potentially large body weight loss and a related proportionally large loss in lean body mass at altitude had not been addressed directly and could not easily be determined. However, based on physical performance data previously collected at sea level it seemed likely that a large loss in lean body mass would be detrimental to physical performance tasks that depended primarily on endurance and/or muscle strength. For example, previous studies conducted at sea level indicated that three or more weeks of similar energy imbalances (e.g., -1500 to -2000 kcal•day^{-1}) resulted in ~10% reduction in $\dot{V}O_2$max (31) and likely proportional declines in submaximal exercise performance (15).

In the present study, total body water after three weeks at altitude declined similarly (-6%) from sea level for both the adequately fed and caloric-deficit groups. Physical performance changes at altitude were also quite similar for both groups. The reason for the similar decline in total body water despite a significant difference in body weight loss is not well understood; but it should be noted that the HYPO group (i.e., the group that remained at sea level and that had a 5% body weight loss) also had a similar

loss in total body water. Collectively, these data suggest that there is a fixed total body water volume that can be lost due to either body weight losses of 5 to 8% or 3 weeks of altitude exposure, or both.

Shell-loading task performance for the HYPO group at sea level improved in proportion to losses in body weight and body fat during the 21 days of the dietary phase. Similarly, both the DEF and ADQ groups improved shell-loading task performance with continued altitude exposure, with the improvement being somewhat greater and occurring more rapidly for the DEF group who lost more body weight and body fat compared to the ADQ group. Thus, despite large differences among groups in losses of body weight, lean body mass and, fat body mass, these results indicate that all groups improved performance during a task requiring body movement against gravity with the improvement being somewhat greater for the two groups that lost significant amounts of body weight and fat body mass.

Previous studies at 4300 m altitude indicate that local muscle endurance performance during activities lasting longer than approximately two minutes is impaired during initial exposure (9;12) compared to sea level and is due to a diminution in the *rate* of oxygen diffusion from capillary to mitochondria of active muscle resulting from a reduced oxygen pressure gradient (7). Consequently, to support the required rate of ATP turnover, the contribution of anaerobic metabolism grows (30) resulting in an increase in the concentration of associated metabolic byproducts (e.g., H^+ and P_i (30)). During altitude acclimatization, ventilatory, hematological, and metabolic changes augment the blood-to-tissue oxygen gradient, local concentration of metabolites is reduced, and local muscle endurance performance is improved (9). These results and interpretations are consistent with findings in the present study that show a tendency for local muscle endurance performance to decline during the adductor pollicis muscle fatigue task within the first three days of altitude exposure and then subsequently improve with continued exposure.

Prior to the present study, the effect of large losses in body weight and lean body mass on local muscle performance during altitude acclimatization could not be predicted. On the one hand, previous studies of severe hypocaloric diets at sea level have resulted in impaired skeletal muscle contractile function of the adductor pollicis muscle (28), probably by decreasing phosphofructokinase and succinate dehydrogenase activities (29) and causing a fall in muscle creatine phosphate content (26). Thus, performances during the adductor pollicis muscle endurance and the one-arm curl tasks at altitude were expected to be impaired during large body weight loss. On the other hand, it could also be expected that losses of intra- and extracellular fluid would increase the capillary-to- muscle fiber density and decrease the oxygen diffusion distance from capillary to mitochondria. Such change at altitude would tend to improve the rate of tissue oxygenation and local muscle task performances (9). In the present study, there was no difference between groups at altitude in local muscle performance during either the adductor pollicis muscle or one-arm curl tasks. Whether the lack of performance impairment in the deficit group during energy intake deficit at altitude was due to an improved tissue oxygenation rate that offset a loss of contractile function or to

a lack of a large body weight loss to affect muscle contractile function cannot be determined at present.

CONCLUSION

We conclude that a substantial caloric deficit of 1500 kcal•day^{-1} for 21 days both at sea level and at 4300 m altitude that caused losses of 5 to 8% in body weight and 3 to 6% in lean body mass, did not adversely affect maximal or submaximal physical performance.

REFERENCE LIST

1. Baker-Fulco CJ: Overview of dietary intakes during military exercises. In: Not Eating Enough. Edited by Marriot BM. Washington, D.C., National Academy Press, 1995.
2. Baker CJ, Rock PB, Fulco CS, Trad LA, Cymerman A: High altitude-induced anorexia. FASEB J. 1989; 3:A98.
3. Boyer SJ, Blume DF: Weight loss and changes in body composition at high altitude. J.Appl.Physiol. 1984; 57:1580-1585.
4. Butterfield GE: Maintenance of body weight at altitude: in search of 500 Kcal/day in Nutritional Needs in Cold and in High-Altitude Environments. Edited by Marriot BM, Carlson SJ. Washington,D.C., National Academy Press, 1996.
5. Butterfield GE, Gates J, Fleming S, Brooks GA, Sutton JR, Reeves JT: Increased energy intake minimizes weight loss in men at high altitude. J.Appl.Physiol. 1992; 72:1741-1748.
6. Edwards, J. S. A., Askew, W. E., King, N., Fulco, C. S., Hoyt, R. W., and Delany, J. P. An assessment of the nutrition intake and energy expenditure of unacclimatized US Army soldiers living and working at high altitude. T10-91, 1-144. 1991. Natick,MA, USARIEM.
7. Eiken O, Tesch PA: Effects of hyperoxia and hypoxia on dynamic and sustained static performance of the human quadriceps muscle. Acta Physiol.Scand. 1984; 122:629-633.
8. Friedl KE: Introduction and Background. In: Not eating enough. Edited by Marriot BM. Washington, D.C., National Academy Press, 1995.
9. Fulco CS, Cymerman A, Muza SR, Rock PB, Pandolf KB, Lewis SF: Adductor pollicis muscle fatigue during acute and chronic altitude exposure and return to sea level. J.Appl.Physiol. 1994; 77:179-183.
10. Fulco CS, Cymerman A, Pimental NA, Young AJ, Maher JT: Anthropometric changes at high altitude. Aviat.Space.Environ.Med. 1985; 56:220-224.
11. Fulco CS, Hoyt RW, Baker-Fulco CJ, Gonzalez J, Cymerman A: Use of bioelectrical impedance to assess body composition changes at high altitude. J.Appl.Physiol. 1992; 72:2181-2187.
12. Fulco CS, Lewis SF, Frykman P, Boushel R, Smith S, Harman EA, Cymerman A, Pandolf KB: Muscle fatigue and exhaustion during dynamic leg exercise in normoxia and hypobaric hypoxia. J.Appl.Physiol. 1996; 81:1891-1900.
13. Fulco CS, Rock PB, Cymerman A: Maximal and submaximal exercise performance at altitude. Aviat.Space Environ.Med. 1998; 69:793-801.
14. Fulco CS, Rock PB, Muza SR, Lammi E, Cymerman A, Butterfield GE, Moore LG, Braun B, Lewis SF: Slower fatigue and faster recovery of the adductor pollicis muscle in women matched for strength with men. Acta Physiol.Scand. 1999; 167:233-239.
15. Gleser MA, Vogel JA: Effects of acute alterations of VO2max on endurance capacity of men. J.Appl.Physiol. 1973; 34:443-447.

16. Hackett PH, Rennie D, Grover RF, Reeves JT: Acute mountain sickness and the edema of high altitude. Respir.Physiol. 1981; 46:383-390.

17. Horstman D, Weiskopf R, Jackson RE: Work capacity during 3-wk sojourn at 4,300m: effects of relative polycythemia. J.Appl.Physiol. 1980; 49:311-318.

18. Jain SC, Bardhan J, Swamy YV, Krishna B, Nayar HS: Body fluid compartments in humans during acute high-altitude exposure. Aviat.Space Environ.Med. 1980; 51:234-236.

19. Jones, T. E., Hoyt, R. W., Baker, C. J., Hintlian, C. B., Walczak, P. S., Kluter, R. A., Shaw, C. P., Schilling, D., and Askew, E. W. Voluntary consumption of a liquid carbohydrate supplement by special operations forces during a high altitude cold weather field training exercise. Technical Report.US Army Res.Inst.Environ.Med. T20-90. 1990.

20. Kayser B: Nutrition and high altitude exposure. Int.J.Sports Med. 1992; 13 Suppl 1:s129-s132.

21. Krzywicki HJ, Consolazio FC, Johnson HL, Nielsen WC, Barnhart RA: Water metabolism in humans during acute high altitude exposure (4,300m). J.Appl.Physiol. 1971; 30:806-809.

22. Lukaski HC, Bolonchuk WW: Estimation of body fluid volumes using tetrapolar bioelectrical impedance measurements. Aviat.Space Environ.Med. 1988; 59:1163-1169.

23. Maher JT, Jones LG, Hartley LH: Effects of high-altitude exposure on submaximal endurance capacity of men. J.Appl.Physiol. 1974; 37:895-898.

24. Morgan, T. E., Hodges, L. A., Schilling, D., Hoyt, R. W., Iwanyk, E. J., McAninch, G., Wells, T. C., and Askew, E. W. A comparison of the meal, ready-to-eat, ration, cold weather, and ration, light weight nutrient intakes during moderate altitude cold weather field training operations. Technical Report.US Army Res.Inst.Environ.Med. T5-89. 1988.

25. Orizio C, Esposito F, Veicsteinas A: Effect of acclimatization to high altitude (5,050 m) on motor unit activation pattern and muscle performance. J.Appl.Physiol. 1994; 77:2840-2844.

26. Pichard C, Vaughan C, Struk R, Armstrong RL, Jeejeebhoy KN: Effect of dietary manipulations (fasting, hypocaloric feeding, and subsequent refeeding) on rat muscle energetics as assessed by nuclear magnetic resonance spectroscopy. J.Clin.Invest. 1988; 82:895-901.

27. Rose MS, Houston CS, Fulco CS, Coates G, Sutton JR, Cymerman A: Operation Everest. II: Nutrition and body composition. J.Appl.Physiol. 1988; 65:2545-2551.

28. Russell DM, Leiter LA, Whitwell J, Marliss EB, Jeejeebhoy KN: Skeletal muscle function during hypocaloric diets and fasting: a comparison with standard nutritional assessment parameters. Am.J.Clin.Nutr. 1983; 37:133-138.

29. Russell DM, Walker PM, Leiter LA, Sima AAF, Tanner WK, Mickle DAG, Whitwell J, Marliss EB, Jeejeebhoy KN: Metabolic and structural changes in skeletal muscle during hypocaloric dieting. Am.J.Clin.Nutr. 1984; 39:503-513.

30. Sahlin K: Metabolic changes limiting muscle performance in Biochemistry of Exercise VI. Edited by Saltin B. Champaign,IL, Human Kinetics, 1986.

31. Taylor HL, Buskirk ER, Brozek J, Anderson JT, Grande F: Performance capacity and effects of caloric restriction with hard physical work on young men. J.Appl.Physiol. 1957; 10:421-429.

32. Wright HF, Wilmore JH: Estimation of relative body fat and lean body weight in a United States Marine Corps population. Aerospace Med. 1974; 45:301-306.

33. Young AJ, Evans WJ, Cymerman A, Pandolf KB, Knapik JJ, Maher JT: Sparing effect of chronic high-altitude exposure on muscle glycogen utilization. J.Appl.Physiol. 1982; 52:857-862.